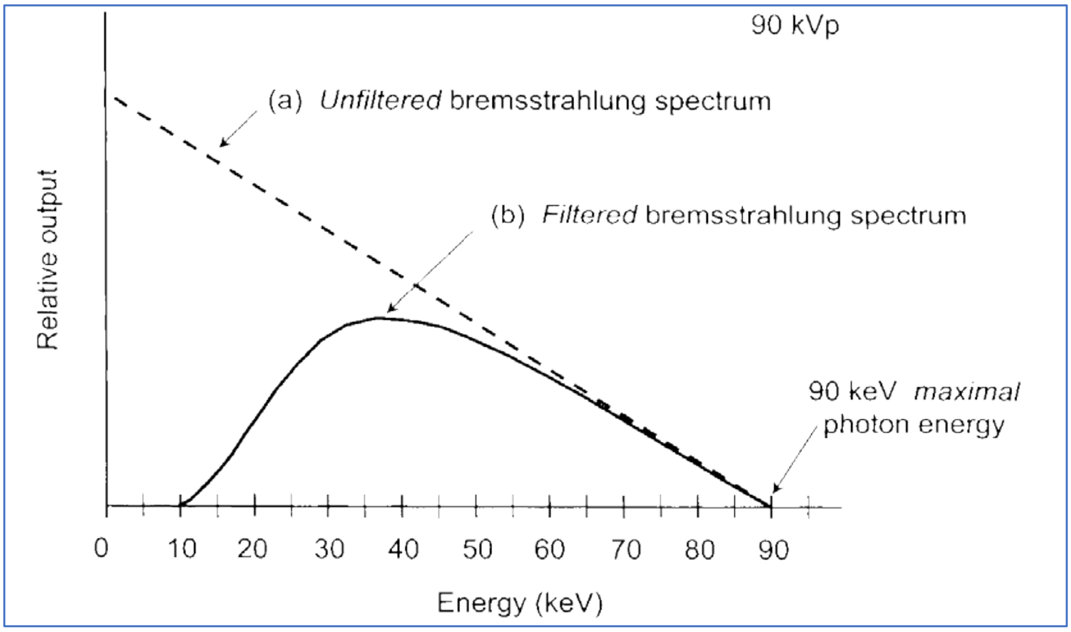
NOTES: PHYS1250

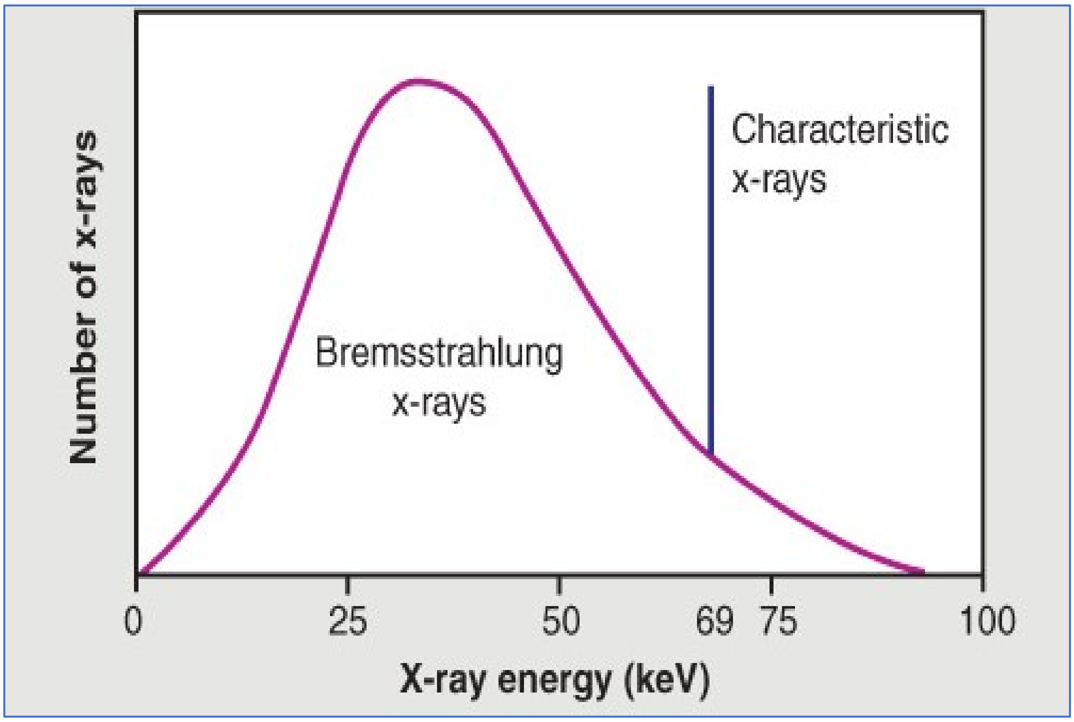
Lecture 1: The Diagnostic and Superficial X-ray Spectrum

Discuss all aspects of the Bremsstrahlung and Characteristic x-ray spectrums.

- Bremsstrahlung/breaking radiation is produced when fast moving electrons interact near the nucleus of the target atom. They are slowed down by the attractive coulomb force of the nucleus.
- The incident electron may lose all/some of its energy. The closer it comes to interacting with the nucleus, the greater the energy of the radiation. An incident electron which does not lose all its energy in one interaction may lose more energy following interaction with another nucleus. Usually many x-ray/photons/radiation is emitted.
- The maximum energy of the x-ray/photon/radiation indicates the kVp used i.e. the incident electron energy accelerated through 90kVp acquires 90 keV of x-ray/photon/radiation energy.
- Bremsstrahlung spectrum
    - Filtration occurs inherently to adjust the energy of the photons i.e. glass envelope, oil and exit window of tube housing. Filtration removes low energy photons.
    - The filtered spectrum peak occurs at approximately 1/3 of the maximal photon energy. This is dependent on total filtration, kVp and target material.
    - Photon energy of 40keV is the most common relative output.
    - The maximal photon energy is 90keV.
    - Heterogeneous beam as there are photons of different energies.



- Characteristic radiation is produced when fast moving electrons interact with the electron of inner shells i.e. K shell of the target atom. The incident electrons removes the electron of inner shells. KE is shared between the incident electron and binding energy of the electron of inner shell. The vacancy in the K shell is filled but an electron of immediate outer shell, the balance in binding energies is emitted as an x-ray photon.
- The characteristic spectrum appears at discrete energies unlike the Bremsstrahlung spectrum.



Familiarise with the emission spectrum and determinants of its quality and quantity.

- The emission spectrum includes bremsstrahlung and the characteristic radiation.
- At 100 kVp tungsten target, the characteristic radiation makes up approximately 15% of the useful x-ray beam and the bremsstrahlung radiation makes up the rest.
- Determinants of proportion is kVp, the target material and filtration.
- The emission spectrum can be described using the following terms: quantity, quality and intensity.
- Quantity is a measure of the number of photons in the beam. An increase in the quantity is reflected in an increase in the amplitude of the spectrum.
- Quality is a measure of the penetrative ability of the beam. A hard beam is more penetrative with higher energy photons. It is defined by the half value layer and effective photon energy. Half value layer/HVL/ half value thickness is a measure of the thickness of a given material which will reduce the intensity of the beam by 50%. Effective photon energy is a theoretical concept, a monochromatic x-ray beam of a specified energy e.g. 50 keV photons which has the same penetrating power as the heterogenous beam indicates that the effective photon energy of 50 keV.

Know the factors that control the emission spectrum.

- Factors that control the emission spectrum include kVp, mA & s/mAs,), filtration (fixed/unfixed), distance from x-ray source (fixed in an x-ray unit). Other factors include target material and voltage waveform/ripple.

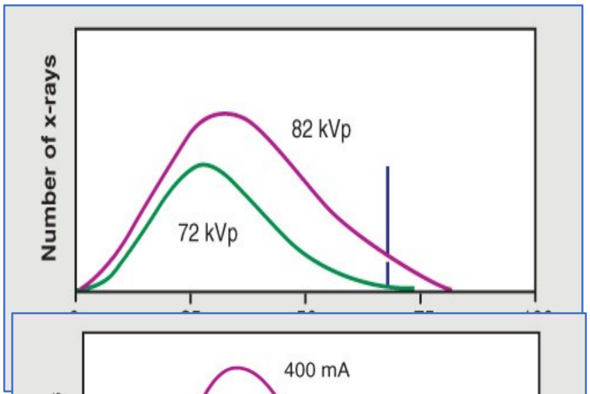
Explain the effect of kVp, mA, mAs, added filtration, waveform, target material, voltage ripple and distance on the emission spectrum.

- kVp is the acceleration provided to the incident electrons. As the kVp increases, the quality increases and a hard beam/higher energy photons are produced. The emission spectrum shifts to the right.

Example: Tungsten target

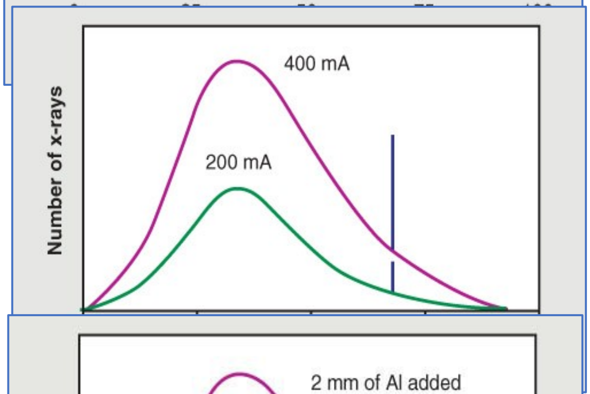
As kVp increases:

- The maximum photon energy increases
- The peak moves to the right indicating higher quality
- Amplitude increases
- Characteristic spectrum may become visible if incident electron energy exceeds the K shell binding energy.



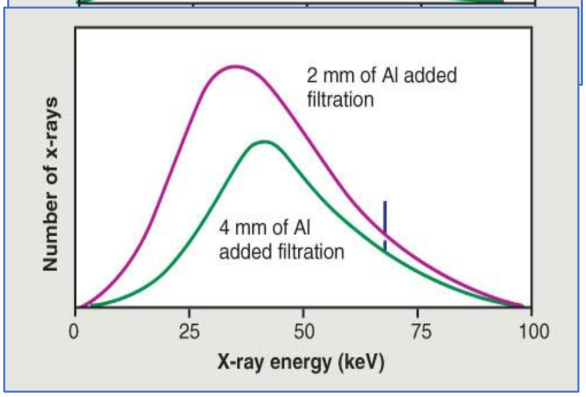
As mAs/mA & s increases:

- The maximum photon energy does not increase
- The peak does not move to the right
- Amplitude increases
- Beam intensity is proportional to $I_2/I_1 = (mAs)_2/(mAs)_1$



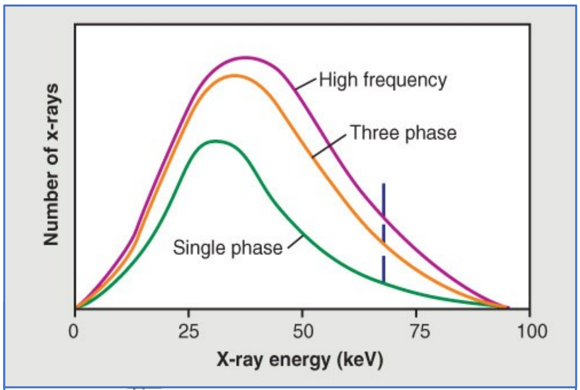
As filtration increases:

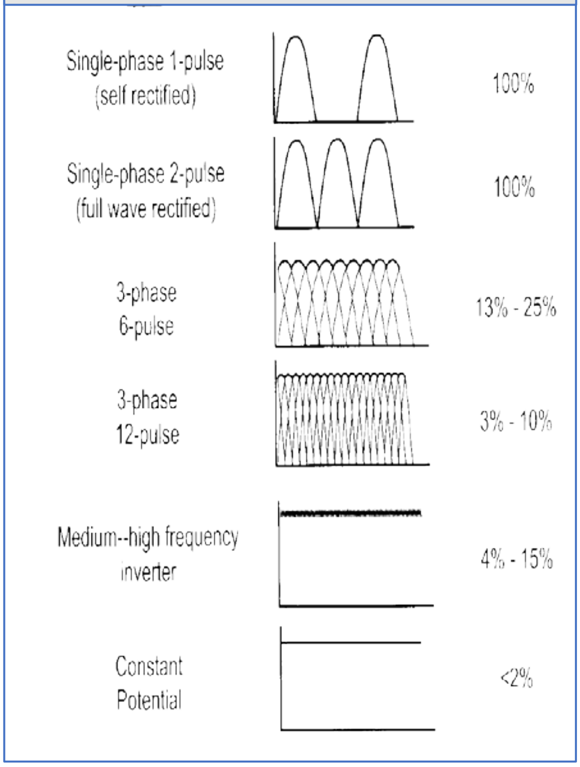
- The maximum photon energy does not increase
- The peak moves to the right
- Amplitude decreases
- Lower energy photons are removed
- Total filtration includes the effect of inherent and additional filtration



Voltage waveform (ripple):

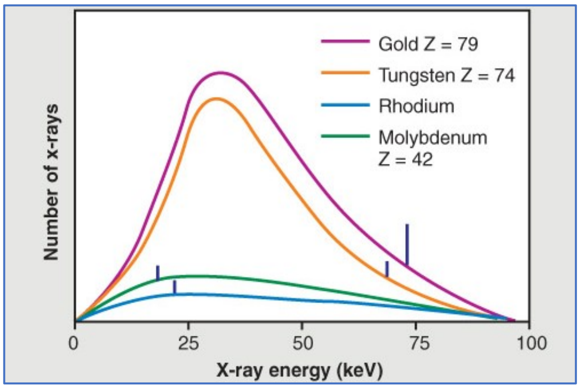
- Voltage waveform (ripple) applied to the x-ray tube affects the emission spectrum.
- Ripple is proportional to the square of kVp. Few x-rays of lower energy are produced (quantity) at low kVp, More x-rays of higher energy are produced at high kvP
- Ripple is proportional to mAs
- As the ripple decreases: the maximum photon energy does not increase, the peak moves to the right, amplitude increases.
- Factor is determined by the equipment purchased





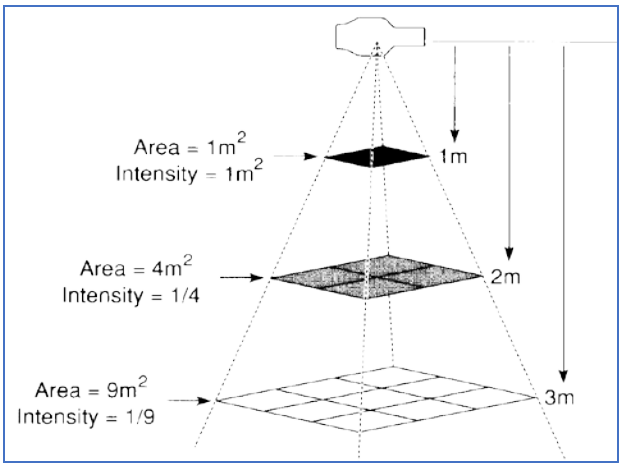
As the Z of target material increases:

- The efficiency of bremsstrahlung radiation increases
- The maximum photon energy does not increase
- The peak moves to the right
- Amplitude increases
- Characteristic radiation occurs at higher energies/kVp
- Rhodium is an except to the trend
- Factor is determined by the equipment purchased



Distance from source:

- The inverse square law (ISL) applies to radiation emitted by a point source.
- Intensity is inversely proportional to the square distance from the source. As the distance increases, the beam covers a large area.
- Absorption in air is disregarded.



Lecture 2: Image Quality in Diagnostic Radiography

Understand the basic requirements of a radiographic procedure.

- Diagnostic image produced at the lowest dose.
- Diagnostic image has one-one relationship with the anatomical part.
- Diagnostic image has adequate radiographic contrast (differences in shades of grey) and detail (resolution). This allows better examination of small and large structures.

List the fundamental terms used to discuss image quality.

- Radiographic contrast includes detector contrast and subject contrast.
- Radiographic detail (resolution)
- Radiographic distortion includes shape distortion and size distortion

Define the terms used in image quality in diagnostic radiography.

- Radiographic contrast includes detector contrast and subject contrast. Radiographic contrast describes the differences in shades of grey. It allows anatomical parts to be distinguished from each other in the image.
- Detector contrast describes the difference in shades of grey in terms of equipment setting. It is dependent on the detector to produce image contrast. Dynamic Range expresses the range of input signals over which the image receptor is sensitive. In digital radiography, it is about four orders of magnitude.
- Subject contrast describes the differences in shades of grey in terms of the x-ray intensities emerging from the patient. It is dependent on the penetration of the beam. Penetration of the beam is dependent on patient thickness, thickness of tissue (greater differences increases contrast), atomic number, density, electron density, energy of the primary radiation (kVp, higher kVp increases penetration but reduces contrast and increases scatter). Contrast mediums may be introduced into cavities to increase contrast e.g. Barium in fluoroscopy to radiation can be reabsorbed.
- Radiographic detail (resolution)/ spatial resolution describes the sharpness of an image, the capacity for distinguishing fine detail in an image, minimal resolvable separation between high contrast objects. The unit used to define spatial resolution is line pairs per millimetre (lp/mm) i.e. the more lp/mm that can be distinguished, the better the spatial resolution of the system, the average observer is able to view 6 lp/mm with no magnification. It is dependent on the detector (pixel size, detector system, crystal material), geometric (focal spot size/FSS, focus detector distance/FDD and object detector distance/ODD/object-image distance/OID) and motion (voluntary/involuntary).
- Radiographic detail is dependent on detector pixel size i.e. smaller pixel increases spatial resolution, detector system i.e. computed radiography, indirect digital, direct digital and crystal material i.e. structured/unstructured scintillators.
- Radiographic detail is dependent on geometric focal spot size i.e. there are two focal spot sizes, the small spot size is used for detail work, the large spot size is used for high exposure examinations, smaller spot size reduces penumbra, focus detector distance i.e. larger FDD increases spatial resolution, object-detector distance i.e. patient and detector closeness increases spatial resolution.
- Radiographic detail is dependent on voluntary motion i.e. motion that can be controlled with conscious effort or immobilisation devices, involuntary motion i.e. physiological activities such as the heart beat are compromised with kVp-mAs relationships such as high kVp: low mAs, high mA: low s, FDD small FDD: low mAs)
- Radiographic distortion includes shape distortion and size distortion. Shape distortion is elongation. Size distortion is magnification.
- Radiographic shape distortion is caused by angulation and can be avoided by ensuring the plane of anatomical part is parallel to plane of image receptor and x-ray beam is centred and perpendicular to both of these.
- Radiographic size distortion is caused by magnification and can be compromised by inability to place the anatomical part on the detector, inability to have a large source to image distance, patient conditions and physical environment.

Discuss the factors affecting image quality.

- Radiographic detail is dependent on voluntary motion i.e. motion that can be controlled with conscious effort or immobilisation devices, involuntary motion i.e. physiological activities such as the heart beat are compromised with kVp-mAs relationships such as high kVp: low mAs, high mA: low s, FDD small FDD: low mAs)
- Radiographic size distortion is caused by magnification and can be compromised by inability to place the anatomical part on the detector, inability to have a large source to image distance, patient conditions and physical environment.

Discuss the methods used to reduce scatter in diagnostic radiography.

- Methods used to reduce scatter in diagnostic radiography include decreasing the kVp, reducing the field size, decreasing thickness via compression, radiographic grid and air gap.
- Decreasing the kVp increases the likelihood of photoelectric effect and minimises the likelihood of Compton scattering.
- Reducing the field size using tight beam collimation via light beam diaphragm (LBD). A light source makes localisation of the x-ray field possible co-incident with x-rays. It is constructed of two sets of apertures where one set is located near the tube altering the shape and the second set reduces secondary radiation produced by the first set. Plastic covering has a central cross that marks the centre of the x-ray field.
- Decreasing thickness via compression.
- Using a radiographic grid placed between the patient and the image receptor. It includes strips of dense material separated by material transparent (air, plastic, paper) to x-ray all enclosed in aluminium to give support and reduce moisture. The strip material should be thin, have good absorption properties i.e. lead or other high atomic weight materials) and are malleable. Interspace material should maintain

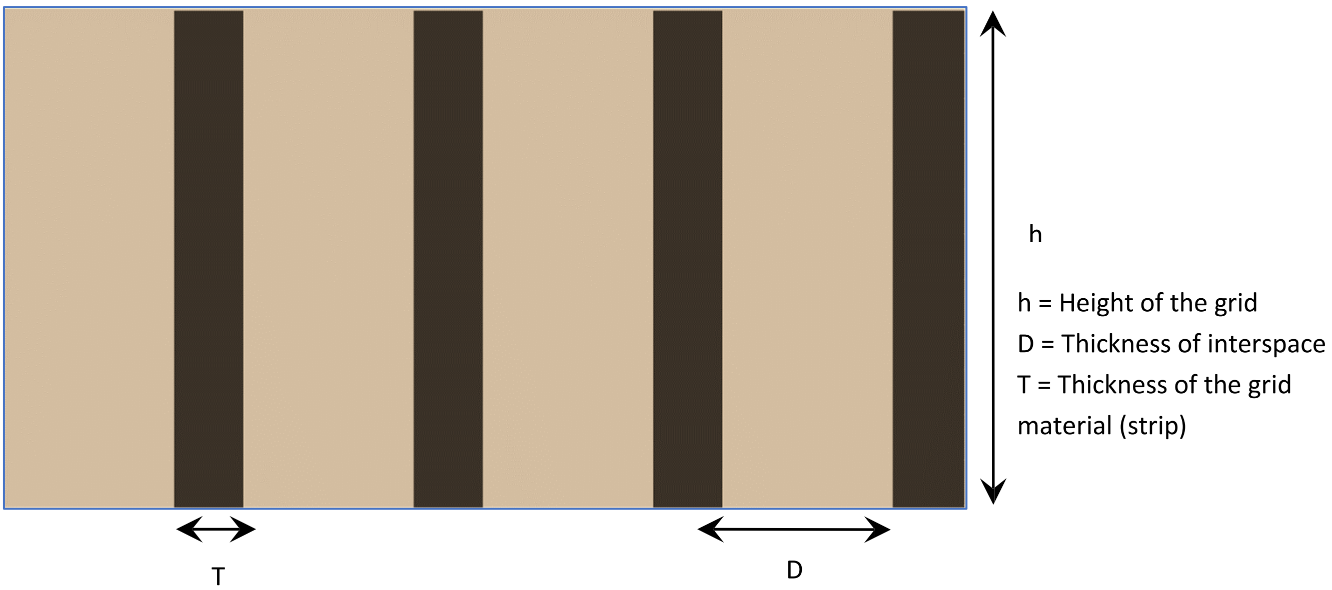
separation between strips, light atomic weight materials i.e. aluminium has higher atomic number, better filtration of scattered photons, produces less grid lines, higher patient dose, insoluble, easy to manufacture.

- The Grid Ratio is the ratio of the height of a strip to the width of the interspace.
- Grid Ratio = height of grid/thickness of interface material
- Values between 4 and 16 are common and can range from 2, 4, 8, 10, 12, 16 dependent on thickness of body part. Greater grid ratios are more effective, are more expensive and deliver higher doses. A grid ratio of 2 reduces the scatter radiation by 50%.
- The Grid Frequency is the number of grid strips per cm.
- Values between 20-80 lines per cm are common. Frequencies range from 25-45 lines per cm. High grid frequencies show less distinct grid lines due to thinner interspace material however at the expense of higher radiation dose.
- The Grid/Bucky Factor is the exposure i.e the mAs increase required because of x-ray absorption by the grid material.
- Values usually exist between 4x-10x.

Bucky Factor			
Grid Ratio	70 kVp	90 kVp	120 kVp
No grid	*1*	*1*	*1*
5:1	*2*	*2.5*	*3*
8:1	*3*	*3.5*	*4*
12:1	*3.5*	*4*	*5*
16:1	*4*	*5*	*6*

- The Grid Cut-Off is the undesirable absorption of primary radiation by the grid. It occurs as the primary x-ray are prevented from reaching the detector. It commonly occurs with linear grids.
- Grids include parallel, focused, crossed and moving. Parallel grids are lead strips arranged parallel to each other and perpendicular to the incident radiation beam. These are not really used in diagnostic radiography unless the radiation field is extremely small. Focused grids are lead strips angled obliquely towards the midline so line focus is obtained at a specific distance. It is important that anode is positioned at the focal point of the grid (midpoint of the convergent lines). Crossed grids are two sets of lead strips (parallel/focused) at right angles to each other. Moving grids are lead strips moving to remove any shadows generated by the grid lines during x-ray exposure.

- Increasing the patient to detector distance using an air gap. This involves positioning the patient away from the detector. A portion of the scattered x-rays generated in the patient are scattered away from the detector and will not be detected. A thicker anatomical part benefits from a greater air-gap width. The first inch (2.54cm) of an air gap improved contrast significantly. Technique is less effective at the higher



energies as scattered radiation is more forward. Image detail/resolution is compromised with increasing FDD.

- Distance is usually 10-15cm.

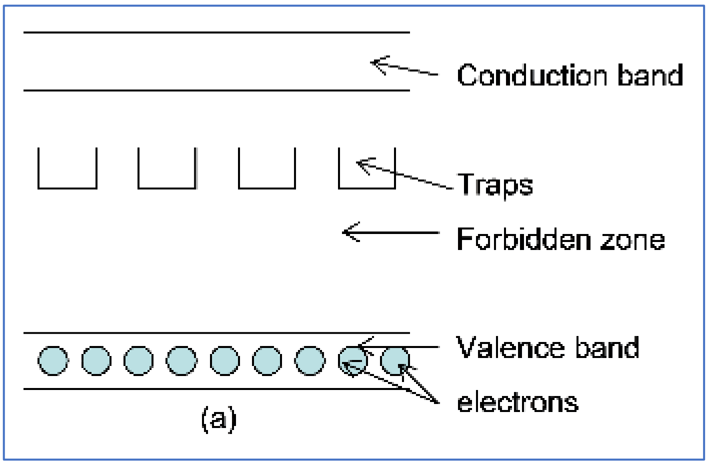
Lecture 3: Detectors in Diagnostic Radiography

Provide an overview of digital imaging.

- Digital imaging of the patient includes generation (acquisition), processing, archiving (Radiology information system/RIS or Hospital information system/HIS) and presentation of the image.
- Generation/acquisition involves detector exposure to x-rays, energy absorbed is transformed into electrical charges, charges is transformed/digitised/quantified into a grey scale.
- Post processing involves organising raw data into clinically relevant image via software.
- Archiving involves images sent to digitised storage archive. A digital header file contains patient demographic information linked to each image.
- Presentation of the image involves image viewed digitally on a computer work station/hard-copy film. Digital images can be manipulated during viewing e.g. panning, zooming, and inverting the grey scale, measuring distance and angle and windowing.

Describe the energy band theory and identify its three distinct areas.

- Following radiation exposure, the fluorescence of materials is explained using the Energy Band Theory. The ranges of energy that an electron can have within the crystal are called energy bands/allowed bands. The ranges of energy that electron cannot have within the crystal are called forbidden bands/band gaps. There are two allowed bands and one forbidden band.
- Allowed bands include valence band and conduction band. The valence band is occupied by outer shell electrons. Conduction bands is occupied by outer shell electrons which have left the atom.



- Forbidden band is not occupied by electrons under normal circumstances. However, impurities and lattice defects (manufacture defect or purpose) in the crystal may generate intermediate energy levels. These energy levels trap electrons.

Explain how electrons move according to the energy band theory.

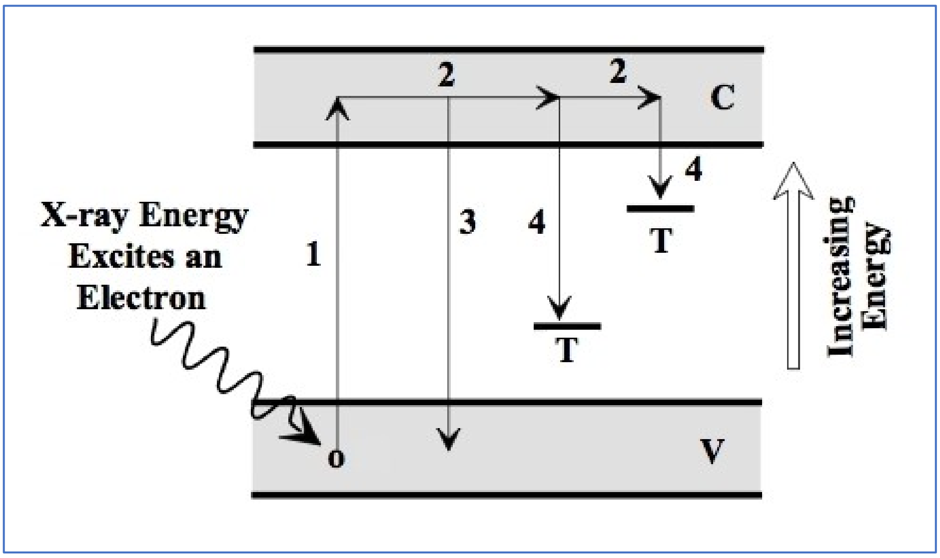
- Movement of electrons occur when the crystal is given sufficient energy to overcome the energy gap, excited electrons move from valence band to the conduction band. This an unstable state therefore electrons will want to drop back to lower energies via dropping straight to valence band emitting visible light and/or UV radiation or drop into traps in the forbidden band.
- Electrons that drop into traps in the forbidden band remain until more energy is given to release it. Energy given can be heat or laser light. The energy given remove electrons from traps to the conduction band. From the conduction band, these electrons will fall back to the valence band emitting light.

List the three types of detector designs in digital radiography.

- The three types of detector designs in digital radiography is computed radiography, indirect digital radiography and direct digital radiography

Describe the principles of operation for each design.

- Computed radiography (Stage 4) involves a cassette placed into a separate reader, x-ray is converted to light and light is converted into charge. Electrons move from valence band to conduction band to forbidden band. Laser light in photostimulable luminescence (PSL) process removes electrons from forbidden band to conduction band to valence band.
- Indirect digital radiography (Stage 3). Electrons move from valence band to conduction band to valence band.
- Direct digital radiography (Stage 2) produces better images with lower radiation doses. Electrons move from valence band to conduction band. The flow of current in the conduction band is used for image production, the crystals used in this process include amorphous selenium.



Describe the design features of the detectors.

- Computed radiography (CR) uses an imaging plate (IP). The imaging plate/storage phosphor screen consists of thin layer of /photostimulable phosphor approximately 0.1-0.3mm on transparent plastic substrate housed in a special cassette. The PSP consists of a family of phosphors BaFX:Eu2+ where X can be any or mixtures of the halogens Cl, Br, I.
- Spontaneous phosphorescence means 25% of stored signal is lost between 10min-8hr after x-ray exposure. This causes fading of image.
- The imaging plate/storage phosphor screen is placed under the body part to be examined and x-ray exposure is made. Incident radiation excites electrons from the valence band to the conduction band to the forbidden band. Photostimulable phosphors absorbs x-ray energy in crystal structure creating a latent image.
- The imaging plate/storage phosphor screen are scanned in separate CR reader device. Red light emitting diodes scans the SPS pixel by pixel stimulating emission of blue light. The light is detected by photomultiplier tubes of photodiodes clocked at a specific resolution. The light signal is converted to an electronic signal and amplified. The amplified electronic signal is converted to discrete digital values for each pixel via analogue-to-digital converter (ADC) and placed onto image processor pixel map.
- Residual signal erasure removes residual latent image electrons still trapped in the forbidden band. Most scanners automatically erase IP via red LED lighting, older systems erase via high intensity white light.
- Digital radiography (DR) uses flat panel detectors. The flat panel detectors integrate x-ray sensitive layer (semiconductor), thin film transistor arrays (TFT) and an electronic readable system. Millions of identical semiconductor elements are deposited on substrate material. Each element/pixel has a switch which is connected to a switching control circuitry that operates per row of array. The output from each pixel is connected in columns with individual pre-amplifiers, digitised using ADC and stored in the digital image processor. TFT sizes include 43cm x43cm with more than 9 million pixels, are deposited on glass substrate. The electronic readable system allows active matrix readout, very fast, immediate access to digital image.
- Indirect digital radiography uses flat panel detectors with scintillator layer and a light sensitive TFT photodiode. The scintillator layer absorbs x-ray photons and converts them to light. Phosphor materials (Cesium Iodide or Gadolinium Oxysulphide) can be structured (tall and thin, light is more contained) or unstructured (like tiles, light coming out in all directions). Charged coupled detectors or a flat panel of amphorous silicon photodiode converts light into an electronic charge. The electronic charge is stored in an element until it is read out by the switching control circuitry.
- Structured scintillators consist of phosphor material in needle light structure, needles are perpendicular to the screen surface. This increases the number of x-ray photon interacts and decreases lateral dispersion of light photons. CsI:TI is a structured phosphor, crystals are grown in needle-like structure (5-10µm D and 600µm thick), favourable K absorption edges at 33 keV and 36 keV, fibre optic guidance to photodetector array with minimal lateral dispersion, green light is emitted when light is converted to electrical charge via a-Si.
- Unstructured scintillators increases lateral dispersion and decreases spatial resolution. Gadolinium Oxysulphide is a unstructured phosphor, dispersed powder phosphor consists of 60% phosphor and 40% binder.
- Absorption efficiency for structured phosphors is approximately 4x higher than unstructured phosphor within similar spatial resolution capabilities.
- Direct digital radiography uses flat panel detectors with x-ray sensitive photoconductor and a charge collector TFT. Photoconductor is a flat panel of amorphous selenium (a-Se), electrical fields is applied to panel, x-ray exposure generates electrons and holes within the a-Se layer and the x-ray photons are converted to electrical charge. The electrical charge signal is read out by a-Si pads with TFT array.

Discuss spatial resolution and dose for each detector type.

- The Fill Factor is the percentage of a pixel area which is sensitive to the image signal. It can never be 100% because pixel area needs to accommodate conductors for input and output switching signals and TFT. Typical fill factors are 50-80%.
- Dynamic Range is increased via digital detectors. High dynamic ranges display better contrast in images.
- Spatial resolution is defined by the minimum pixel size.

- Typical pixel sizes are 100-200µm.
- Scatter of x-ray quanta and light photons within detector influences spatial resolution. Spatial resolution is higher in direct digital radiography detectors due to selenium-based. Spatial resolution is higher in indirect digital radiography detectors with structured scintillators over unstructured scintillators.
- According to the Nyquist theorem, given pixel size **a**, the maximum achievable spatial resolution is **a/2**.
- Radiation Dose can be reduced by higher DQE values of digital detectors and higher dynamic range of digital detectors.